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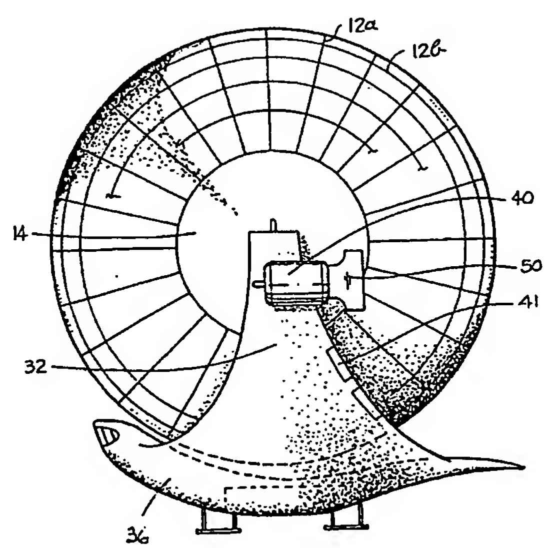
(54) **Aircraft having buoyancy gas balloon.**

(57) An airship having a spherical balloon filled with buoyant gas such as helium at a pressure substantially greater than atmospheric and which is mounted for rotation about a normally horizontal axis, the airship including a rigid load supporting yoke having two support arms extending upwardly from a central gondola and each with an upper end rotatably connected to the balloon, is characterized by the gondola and support arms having surfaces close to and conforming to the shape of the balloon so as to inhibit air flow between the gondola and the bottom of the balloon and to redirect this air to the sides and back of the balloon.



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AIRCRAFT HAVING BUOYANT GAS BALLOON

This invention relates to an aircraft, or airship, in which the major part of the lift is provided by a buoyant gas such as helium. This invention is an improvement on the aircraft described in co-pending European Patent Application No. 80302686.3 filed August 6th, 1980, and which corresponds to U.S. Patent Application Serial No. 64286 filed 6th August 1979.

The aforesaid application described an aircraft using a so-called "super-pressure" balloon which is a generally spherical balloon having essentially fixed dimensions and shape when inflated, and which contains the buoyant gas (normally helium) at a pressure sufficiently high that the shape and size of the balloon is substantially unaffected by normal changes in atmospheric pressure and temperature, even when the balloon has little or no internal supporting structure. Further details concerning the nature of super-pressure balloons and the pressures intended for use in such balloons as used in this invention will be found in the aforesaid application.

As described in the aforesaid application the aircraft further comprises:-

A rigid load support yoke including two arms extending upwardly from a central gondola and each with an upper end,

means rotatably connecting the upper ends of said arms to the balloon in such manner as to allow the balloon

to rotate about a normally horizontal axis passing through the centre of the balloon,

means for propelling the aircraft through the air in a forward direction transverse to said axis, and

means for rotating the balloon about said horizontal axis in such direction that the surface of the balloon facing said forward direction moves upwards relative to the centre of the balloon.

Rotation of the balloon contributes to the lift by virtue of the Magnus effect, which becomes effective when the aircraft is moving forward; for initial lift-off engine thrust may augment the static lift.

An aircraft having the features described above will hereinafter be referred to as an aircraft "of the type described".

The airship described in the aforesaid application had arms and a gondola of airfoil shape, and the arms were curved lengthwise to conform to the shape of the balloon and to position the gondola so that the distance separating the bottom of the balloon from the top of the gondola was less than 1/10 of the balloon radius; this provides good manouverability of the craft as compared to standard balloon construction using cables. The top of the gondola was curved in the longitudinal direction to follow the curve of the balloon down to the fore-and-aft centreline of the craft, beyond which the surface sloped downwards.

The present invention provides an airship which has major features similar to that described in the aforesaid application, but in which the arrangement of gondola and supporting arms is modified to improve the flight characteristics and especially the ratio of lift to drag which can be obtained with a rotating balloon.

In accordance with the present invention, in an aircraft of the type described, the gondola has a portion of its upper surface concavely shaped to conform to the balloon surface both laterally and longitudinally and spaced from said balloon surface by an amount small enough to restrict flow of air between the gondola and the balloon when the aircraft is moving in the forward direction.

A portion, and preferably a major portion of the gondola upper surface may be situated less than 12 inches (30.5 cm) from the closest parts of the balloon surface. This distance will normally be less than 2% of the balloon radius and may be about 1% for a large balloon (say 160 ft. or 50 m. dia.). The restriction of flow between the balloon and the gondola reduces drag since air which would otherwise flow under the forwardly moving bottom surface of the balloon is deflected under the relatively smooth bottom surface of the gondola.

This invention will be described in more detail with reference to the accompanying drawings, in which:-

Fig. 1 is a side elevation of an aircraft of this invention,

Fig. 2 is a frontal elevation of the aircraft of Fig. 1,

Fig. 3 is a view of the underside of the same aircraft, and

Figs. 4, 5 and 6 are views of a model of the aircraft used in wind tunnel tests.

The main components of the aircraft or airship are as described in my aforesaid application, and are as follows:-

a spherical superpressure balloon 10 having circumferential cables 12a;

a rigid load supporting yoke including two arms 32 extending upwardly from a central gondola 36,

shafts 30 rotatably connecting the upper ends of these arms to the balloon to allow the balloon to rotate about a normally horizontal axle 16 passing through its centre,

gas turbine engines 40, mounted adjacent the upper ends of the arms, for propelling the aircraft through the air in a forward direction transverse to the axis, and

means, which may be an electric motor mounted at the top of an arm 32, for rotating the balloon in such direction that the surface of the balloon facing the forward direction moves upward relative to the centre of the balloon, thereby generating a lift by the Magnus effect.

The general details of construction, especially in relation to the balloon material, the means for pressurizing the balloon, the internal cabling to maintain the spherical shape of the balloon, the balloon rotation means, the nature of engines 40, and the general form of the gondola 36 and arms 32 which are provided with rudders 41, are all as described in my aforesaid application. However, the airship of this invention has the following modifications as compared to that of my aforesaid application:-

1) The balloon 10 is modified in that in addition to the circumferential cables 12a, additional cables 12b are provided defining a series of squares over the surface of the balloon. The balloon material bulges slightly between the cables to give a pillowed effect. The size of the irregularities is similar (proportionally to the balloon size) to the dimples of a golf ball, and the effect is intended to be similar to a golf ball in enhancing the Magnus effect and reducing drag.

2) Instead of a single central ballonet which in accordance with my aforesaid application was supported in the centre of the balloon by an axle, two ballonets 24 are used each located at one end of the rotational axis of the balloon. Large end plates 14 are provided to which are attached the ends of cables 12a, and the flexible material of the ballonets 24 is connected and sealed around the periphery of each of the plates. When deflated the ballonet material lies in contact with or close to the adjacent end plate, and when inflated the ballonets assume a roughly hemispherical shape. Air is supplied to the ballonets through tubes which pass up arms 32 and enter the balloon co-axially of shafts 30, each ballonet being supplied by an independent compressor so that the amount of air in the ballonets can be regulated independently to assist trimming the craft. Since the central axle 16 has no ballonet to support, it may be of quite light construction, suitable merely for resisting axial loads.

3) The gondola 36 has its upper surface conforming very closely with the adjacent surface of the balloon; a major portion of the gondola upper surface may be situated less than 12 (30.5 cm.) inches or less than about 2% of the balloon radius from the outermost extremities of the balloon surface. A preferred spacing from the balloon surface outer extremities would be about 1% of the balloon radius or about 25 cm. for a balloon of 50 metres radius. The blanking effect is enhanced by providing not only a concave curvature to a front portion of the gondola top which lies in front of the axle 116, but also to a lesser portion of the rear of the gondola top lying behind the axle 16 so that both portions conform closely to the balloon curvature. By restricting the airflow between the balloon and the gondola, this tends to reduce the drag which would otherwise occur by reason of the roughened bottom surface of the balloon moving forward at perhaps twice the overall speed of the airship. In other words a substantial part of the lower surface of the balloon is blanked off or masked by the gondola and as the airship moves forward air is deflected largely underneath the gondola which offers less resistance to flow than the underside of the balloon. The blanking effect continues to the side margins of the gondola since the gondola top surface is concave laterally as well as longitudinally, and the blanking effect also continues at the lower portions of arms 32 which are wide in the fore-and-aft direction and are also concave internally laterally as well as lengthwise for a major part of their length.

4) The engines 40 are mounted adjacent the upper ends of arms 32 but are situated below the rotational axis of the balloon by an amount equivalent to say 1/5 of the balloon radius, and are at least close to being aligned with the centre of gravity of the whole airship. This positioning of the engines counteracts slight backwards sway of the gondola which will occur upon forwards acceleration with the engines aligned with the balloon axis as in my aforesaid application.

5) Additional control surfaces are provided in the form of thrust deflectors 50 located behind the engines.

The amount of Magnus lift will depend on the forward speed of the airship, rotational speed of the balloon, and surface roughness of the balloon. The following table gives calculated figures approximating what would be the optimum flying conditions for three models of airship of the design illustrated herein, and having balloons respectively of 72, 160 and 200 ft. (22, 49 and 61 metres respectively):-

Model designation	72P	160P	200P
Sphere diameter (ft) (Sphere diameter - metres)	72 (22)	160 (49)	200 (61)
Total sphere volume (cu ft) (Total sphere volume cu metres)	195,500 (5,530)	2,144,500 (60,700)	4,188,800 (118,500)
Total static lift (lb) (Total static lift Kg)	12,900 (5,860)	140,600 (63,800)	274,000 (124,000)
Net weight (lb) (without fuel) (Net weight Kg) (without fuel)	7,000 (3,170)	45,600 (20,700)	99,000 (45,000)
Net static lift (lb) (Net static lift Kg)	5,900 (2,680)	95,000 (43,100)	175,000 (79,500)
Max. Magnus lift (lb) (Max. Magnus lift Kg)	6,000 (2,720)	30,000 (13,600)	40,000 (18,200)
Fuel load (lb) (Fuel load Kg)	2,400 (1,090)	40,000 (18,200)	55,000 (25,000)
Net disposable static lift (lb) (Net disposable static lift Kg)	3,500 (1,590)	55,000 (25,000)	120,000 (54,500)
Net Maximum disposable lift (lb) (Net Maximum disposable lift Kg)	9,500 (4,310)	85,000 (38,600)	160,000 (72,500)
Max. airspeed (mph) (Max. airspeed Kmph)	60 (100)	60 (100)	60 (100)

It may be noted that the figures for Magnus lift are very approximate pending large scale experiments.

It will be seen that Magnus lift can contribute substantially to the net maximum disposable lift, especially in

smaller sizes of the airship. As size increases the toal static lift increases with the cube of the balloon diameter whereas Magnus lift depends on the square of the balloon diameter so that relative amount of Magnus lift diminishes. However in the 160 ft. (49 metre) diameter model the Magnus lift is still more than 40% the net disposable static lift. Even in the 200 ft. (61 metre) dia. model the Magnus lift will still be about 30% of the net disposable static lift and certainly over 25%. Since the Magnus lift depends on speed as well as rotation, in order to take off with a load greater than the net disposable static lift either the airship must be made to move along a runway, or engine thrust must be used to augment static lift; the latter alternative is preferred since the ability to hover is considered important. It is anticipated that during take-off the engines will be orientated so that at least 60% of total engine thrust will be directed downwards to augment the static lift during take-off, and the engines will then be inclined to the horizontal position to propel the airship in the forward direction while the balloon is rotated to supply the Magnus lift. Once cruising speed has been reached, the engines will be used primarily only for forward movement.

In order for the Magnus effect to contribute substantially to the payload, the engines should be capable of developing downwardly directed thrust which is at least 25% and preferably at least 40% of the net disposable static lift; and the balloon surface characteristics and the means for rotating the balloon will be such that at cruising speed the Magnus lift will also be greater than respectively 25% or 40% of the net maximum disposable lift.

The cabling pattern on the balloon may be more complex, and may, for example, give triangular pillowed areas. For this purpose the cables may be arranged in a pattern similar to that of a geodesic dome, or the cabling may be similar to a spherical

icosahedron.

Also, the blanking effect which is described above may be increased by having arms 32 extended rearwardly and conforming closely to the surface of the balloon.

If the gap between the balloon and the gondola upper surface is very small, air entrained by the surface irregularities of the balloon may be drawn forward through the gap between the balloon and the gondola. If the gap is relatively large, air will flow rearwards under the balloon. It is considered preferable that the gap be at an intermediate dimension so that there is a minimum of air flow between the balloon and the gondola.

Wind tunnel tests have been carried out on a model of the airship illustrated in Figs. 4 to 6. The model used a sphere 110 of 12 inches (30.5 cm) having sixteen paddles 112 each 1/4 inch (6 mm) depth, extending over an arc of 90°, and providing surface roughness simulating that produced by cabling in the airship. The gondola 136 of the model was shaped similar to that shown in Figs. 1 to 3, except in having less depth and in having straight sided arms 132. The gondola was spaced from the sphere just enough to clear the paddles, the clearance space being less than 1% of the sphere radius.

The following table shows results for the lift coefficient and drag coefficient C_L and C_D, these quantities being such as satisfy the formulae:

$$\text{Lifting force} = 1/2\ C_L\ \rho S V^2$$

$$\text{Drag force} = 1/2\ C_D\ \rho S V^2$$

where ρ is the density of air

S is the frontal area of the sphere (only)

and V is air speed.

Since the tests were intended to show the effect of various gondola designs on the lift and drag of a particular sphere, the quantity S does not include the gondola area.

The tests were made at various spin rates, given as $\frac{wd}{u}$, where-

w is angular velocity, radius/sec;

d is sphere dia,

u is airspeed

The results of the following table show that, with the masking effect produced by the gondola, drag can be reduced while lift is increased as the rotation speed of the sphere is increased.

TABLE

$\frac{wd}{u}$	C_L	C_D
0.0	-0.18	0.45
0.5	0.12	0.40
1.0	0.13	0.37
1.5	0.13	0.38
2.0	0.15	0.38
2.5	0.13	0.37
3.0	0.14	0.35
3.5	0.15	0.34
4.0	0.17	0.31

CLAIMS:

1. An aircraft comprising:
a generally spherical superpressure balloon for containing a buoyant gas and having essentially fixed dimensions and shape when inflated,

a rigid load support yoke including two arms extending upwardly from a central gondola and each with an upper end,

means rotatably connecting the upper ends of said arms to the balloon in such manner as to allow the balloon to rotate about a normally horizontal axis passing through the centre of the balloon,

means for propelling the aircraft through the air in a forward direction transverse to said axis, and

means for rotating the balloon about said horizontal axis in such direction that the surface of the balloon facing said forward direction moves upwards relative to the centre of the balloon;

wherein said gondola has a portion of its upper surface concavely shaped to conform to the balloon surface both laterally and longitudinally and spaced from said balloon surface by an amount small enough to restrict flow of air between the gondola and the balloon when the aircraft is moving in the forward direction.

2. An aircraft according to claim 1 wherein said concavely curved portion is a major portion of the upper surface of the gondola.

3. An aircraft according to claim 1 or claim 2 wherein said portion is spaced from the closest parts of the balloon surface by an amount less than 2% of the balloon radius.

4. An aircraft according to claim 1 or claim 2 wherein said portion is spaced from the closest parts of the balloon

surface by an amount less than about 1% of the balloon radius.

5. An aircraft according to claim 1 or claim 2 wherein said portion is spaced from the closest parts of the balloon surface by an amount less than 12 inches (30.5 cm).

6. An aircraft according to claim 1 or claim 2 wherein said gondola includes a rear portion lying normally behind said horizontal axis and which curves upwardly from the longitudinal centre of the balloon to conform to the balloon surface.

7. An aircraft according to claim 1 or claim 2 wherein a major portion of adjacent parts of said arms are concave both laterally and longitudinally to conform to the balloon surface.

8. An aircraft according to claim 1 or claim 2 wherein the balloon has a non-smooth surface provided by bulges situated between reinforcing cables lying along the balloon surface.

9. An aircraft comprising:

a generally spherical superpressure balloon for containing a buoyant gas and having essentially fixed dimensions and shape when inflated,

a rigid load support yoke including two arms extending upwardly from a central gondola and each with an upper end,

means rotatably connecting the upper ends of said arms to the balloon in such manner as to allow the balloon to rotate about a normally horizontal axis passing through the centre of the balloon,

means for propelling the aircraft through the air in a forward direction transverse to said axis, and

means for rotating the balloon about said horizontal axis in such direction that the surface of the balloon facing said forward direction moves upwards relative to the centre of the balloon;

wherein said means for propelling said aircraft in a forward direction are engines which are capable of developing downwardly directed thrust which is at least 25% the net disposable static lift, and wherein the means for rotating the balloon, and the balloon surface characteristics, are such that in forward flight the balloon generates a Magnus lift equivalent to at least 25% said net disposable static lift.

10. An aircraft according to claim 9, wherein said engines are capable of developing downwardly directed thrust which is at least 40% the net disposable static lift, and wherein the means for rotating the balloon and the balloon surface characteristics, are such that in forward flight the balloon generates a Magnus lift equivanent to at least 40% said net disposable static lift.

11. An airship according to any of claims 1, 9 or 10, wherein means are provided to allow at least 60% of total engine thrust to be directed downwardly to assist in take-off.

12. An aircraft comprising:

a generally spherical superpressure balloon for containing a buoyant gas and having essentially fixed dimensions and shape when inflated,

a rigid load support yoke including two arms extending upwardly from a central gondola and each with an upper end,

means rotatably connecting the upper ends of said arms to the balloon in such manner as to allow the balloon to rotate about a normally horizontal axis passing through the centre of the balloon,

means for propelling the aircraft through the air in a forward direction transverse to said axis, and

means for rotating the balloon about said horizontal axis in such direction that the surface of the balloon facing said forward direction moves upwards relative to the centre of the balloon;

wherein said means connecting the upper ends of the arms to the balloon include two end plates each attached to a side of the balloon and centred on said axis, and wherein said aircraft further comprises two ballonets located inside the balloon, each ballonet being adjacent one end plate and being formed of flexible material having a periphery sealed around an end plate, each said ballonets being arranged to be supplied with air from an independent source of pressurized air whereby said ballonets may be used both to alter the buoyancy of the aircraft and to trim the craft laterally.

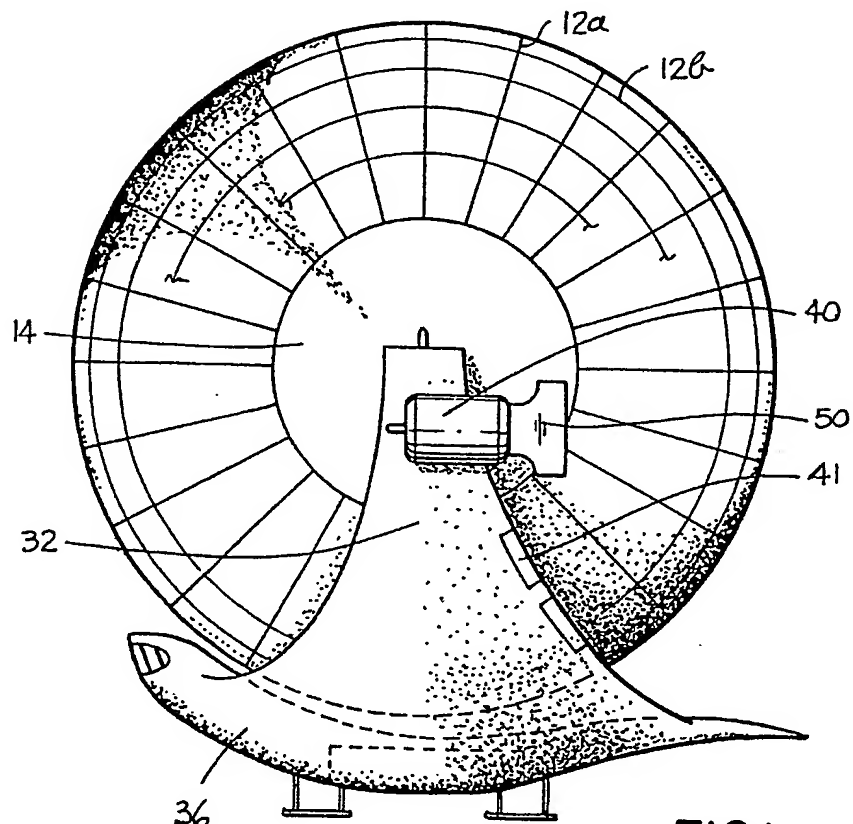

FIG.1

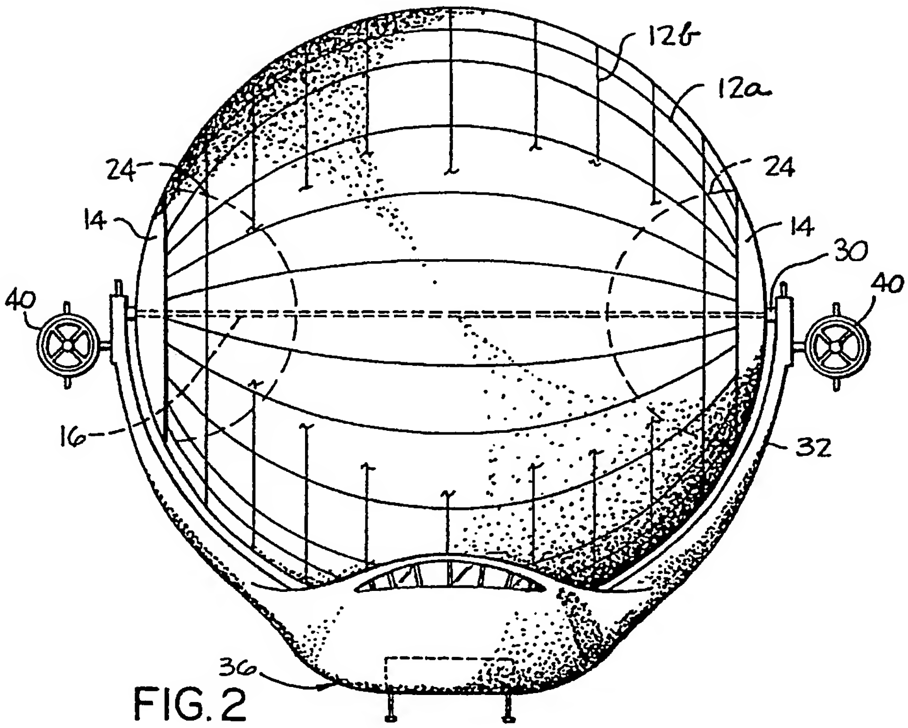

FIG. 2

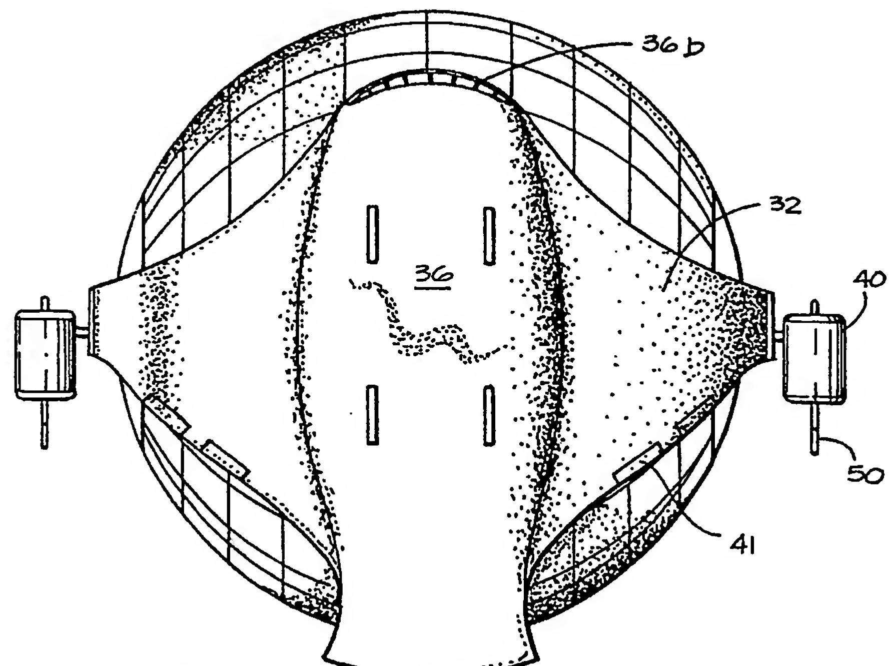

FIG.3

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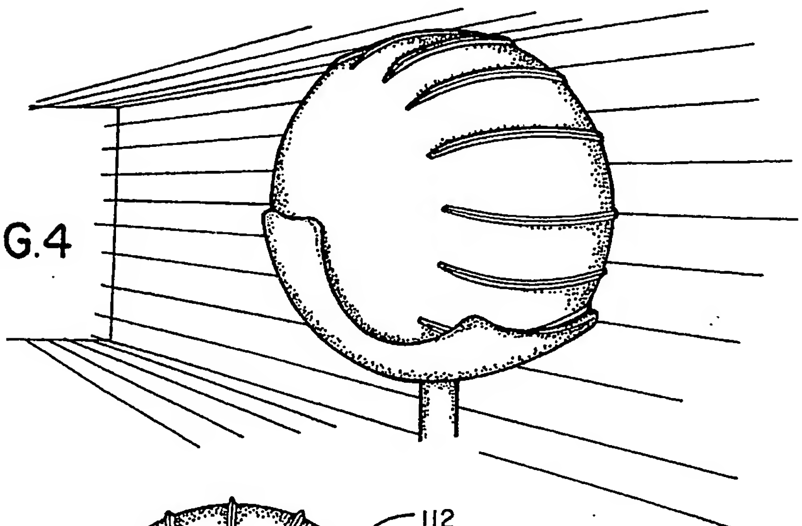
FIG.4



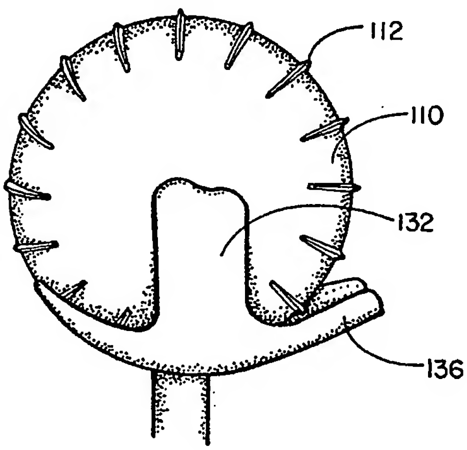


FIG.5

FIG.6